PATENT ABSTRACTS OF JAPAN

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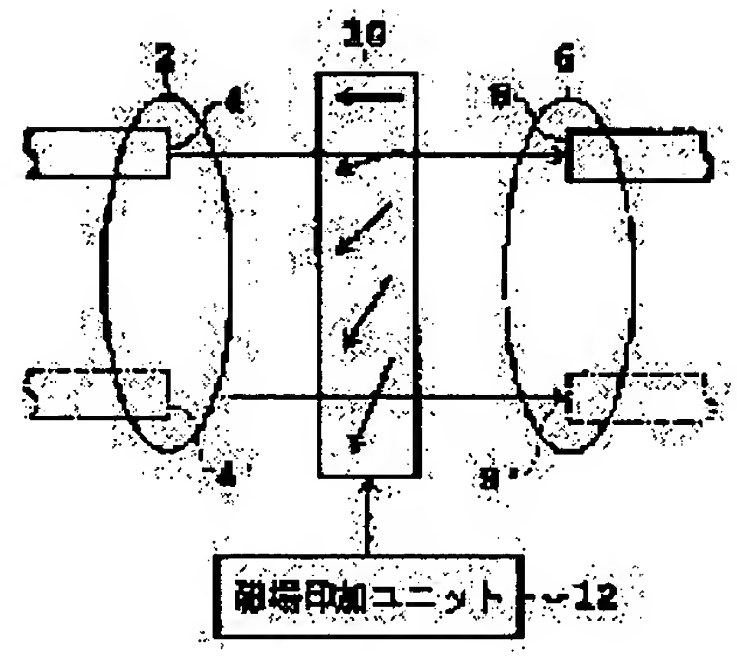
(54) OPTICAL DEVICE USING MAGNET-OPTICAL EFFECT

(57)Abstract:
PROBLEM TO BE SOLVED: To give arbitrary attenuation to an optical signal of each channel for wavelength-division multiplexing(WDM) by applying a magnetic field so that the magnetism of magnetooptic crystal through which a light beam passes has a distribution given in a plane substantially perpendicular to the light beam.
SOLUTION: A light beam outputted from a port 4 is brought into Faraday rotation by axis optical crystal 10 and the light beam is inputted to a port 8. A magnetic field application unit 12 applies the magnetic field to the magnetooptic crystal 10 so that the magnetism of the magnetooptic crystal 10 has the distribution given in the plane substantially perpendicular to the light beam. A 1st area 2 and a 2nd area 6 are so determined that the light beam between the ports 4 and 8 can pass through the magnetooptic crystal 10. Then the distribution of the magnetism imparted to the magnetooptic crystal 10 by the magnetism application unit 12 is so obtained that the magnetism vector slants to the light beam from the top to the bottom in the figure in the plane substantially perpendicular to the light beam.



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CLAIMS

[Claim(s)]
[Claim 1] The optical device equipped with the 1st port located in the 1st field, the 2nd port which is optically combined with this 1st port by the light beam, and is located in the 2nd field, the magneto optics crystal prepared so that the above-mentioned light beam may pass, and a means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the distribution to which magnetization of this magneto optics crystal was substantially given to the above-mentioned light beam at the perpendicular flat surface.
[Claim 2] The means which is an optical device according to claim 1, and carries out the above-mentioned impression is an optical device which consists of two or more magnets and contains at least one electromagnet for two or more of these magnets generating an adjustable magnetic field.
[Claim 3] It is an optical device including a means to be an optical device according to claim 1, and to give change to a means by which the above-mentioned means which carries out impression saturates the intensity of magnetization of the above-mentioned magneto optics crystal, and the direction and strength of the above-mentioned magnetization.
[Claim 4] The means which is an optical device according to claim 1, and carries out the above-mentioned impression is an optical device including a means to change the given distribution, the account of a top.
[Claim 5] The above-mentioned light beam which is an optical device according to claim 1, and passed the above-mentioned magneto optics crystal is an optical device by which Faraday rotation is carried out by the angle of rotation determined by a passage position and the distribution given the account of a top concerned.
[Claim 6] The optical device which is an optical device according to claim 5, and was further equipped with the polarizer formed so that the light beam by which Faraday rotation was carried out [above-mentioned] may pass.
[Claim 7] It is the optical device by which it is an optical device according to claim 1, the 1st port of the above is offered by two or more 1st installed optical fibers, the 2nd port of the above is offered by two or more 2nd installed optical fibers, and each of two or more optical fibers of the above 1st is optically combined with each to which two or more optical fibers of the above 2nd correspond.
[Claim 8] The optical device characterized by providing the following. Two or more 1st optical fibers located in the 1st field. Two or more 2nd optical fibers which is optically combined with each of the optical fiber of this 1st plurality by the light beam respectively, and is located in the 2nd field. The magneto optics crystal prepared so that the above-mentioned light beam may pass. A means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the distribution to which magnetization of this magneto optics crystal was substantially given to the above-mentioned light beam at the perpendicular flat surface, The 1st birefringence crystal which is prepared between two or more optical fibers of the above 1st, and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, The 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and two or more optical fibers of the above 2nd, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[Claim 9] The optical device further equipped with two or more light sources for outputting two or more lightwave signals which have wavelength which is an optical device according to claim 8, is optically connected to two or more optical fibers of the above 1st, respectively, and is different, and the optical multiplexer for connecting with two or more optical fibers of the above 2nd optically, carrying out the wavelength division multiplex (WDM) of two or more above-mentioned lightwave signals, and outputting WDM signal light.
[Claim 10] The optical device which is an optical device according to claim 9, and was further equipped with the light amplifier which is optically connected to the above-mentioned optical multiplexer, and amplifies the above-mentioned WDM signal light.
[Claim 11] The means which is an optical device according to claim 8, and carries out the above-mentioned impression

is an optical device which consists of two or more magnets and contains at least one electromagnet for two or more of these magnets generating an adjustable magnetic field.
[Claim 12] It is an optical device including a means to be an optical device according to claim 8, and to give change to a means by which the above-mentioned means which carries out impression saturates the intensity of magnetization of the above-mentioned magneto optics crystal, and the direction and strength of the above-mentioned magnetization.
[Claim 13] The means which is an optical device according to claim 8, and carries out the above-mentioned impression is an optical device including a means to change the given distribution, the account of a top.
[Claim 14] The optical device characterized by providing the following. A single optical fiber. The dispersive device which combines this optical fiber with two or more light beams from which wavelength differs. Two or more optical fibers with which two or more of these light beams are combined. A means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the magneto optics crystal prepared so that two or more above-mentioned light beams may pass, and the distribution to which magnetization of this magneto optics crystal was substantially given to two or more above-mentioned light beams at the perpendicular flat surface, The 1st birefringence crystal which is prepared between the above-mentioned dispersive device and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, The 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and two or more above-mentioned optical fibers, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[Claim 15] it is an optical device according to claim 14, and has further two or more light sources for outputting two or more lightwave signals which have wavelength which is optically connected to two or more above-mentioned optical fibers, respectively, and is different, and the wavelength division multiplex (WDM) of two or more above-mentioned lightwave signals is carried out by the above-mentioned optical device -- having -- as WDM signal light -- the above -- the optical device outputted from a single optical fiber
[Claim 16] The optical device which is an optical device according to claim 15, and was further equipped with the light amplifier which is optically connected to the optical fiber of the above-mentioned single, and amplifies the above-mentioned WDM signal light.
[Claim 17] The means which is an optical device according to claim 14, and carries out the above-mentioned impression is an optical device which consists of two or more magnets and contains at least one electromagnet for two or more of these magnets generating an adjustable magnetic field.
[Claim 18] It is an optical device including a means to be an optical device according to claim 14, and to give change to a means by which the above-mentioned means which carries out impression saturates the intensity of magnetization of the above-mentioned magneto optics crystal, and the direction and strength of the above-mentioned magnetization.
[Claim 19] The means which is an optical device according to claim 14, and carries out the above-mentioned impression is an optical device including a means to change the given distribution, the account of a top.
[Claim 20] The optical device characterized by providing the following. The 1st optical fiber. The 1st dispersive device which combines this 1st optical fiber with two or more light beams from which wavelength differs. The 2nd optical fiber. The 2nd dispersive device which combines two or more above-mentioned light beams with the 2nd optical fiber of the above, A means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the magneto optics crystal prepared so that two or more above-mentioned light beams may pass, and the distribution to which magnetization of this magneto optics crystal was substantially given to two or more above-mentioned light beams at the perpendicular flat surface, The 1st birefringence crystal which is prepared between the 1st dispersive device of the above, and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, The 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and the 2nd dispersive device of the above, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[Claim 21] The optical device which is an optical device according to claim 20, and is further equipped with the optical multiplexer for connecting with two or more light sources for outputting two or more lightwave signals which have different wavelength, and two or more of these light sources optically, carrying out the wavelength division multiplex (WDM) of two or more above-mentioned lightwave signals, and outputting WDM signal light and by which the above-mentioned WDM signal light is supplied to the 1st optical fiber of the above.
[Claim 22] The optical device which is an optical device according to claim 21, and was further equipped with the light amplifier for amplifying the above-mentioned WDM signal light.
[Claim 23] The means which is an optical device according to claim 20, and carries out the above-mentioned impression is an optical device which consists of two or more magnets and contains at least one electromagnet for two

or more of these magnets generating an adjustable magnetic field.
[Claim 24] It is an optical device including a means to be an optical device according to claim 20, and to give change to a means by which the above-mentioned means which carries out impression saturates the intensity of magnetization of the above-mentioned magneto optics crystal, and the direction and strength of the above-mentioned magnetization.
[Claim 25] The means which is an optical device according to claim 20, and carries out the above-mentioned impression is an optical device including a means to change the given distribution, the account of a top.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] Generally this invention relates to the optical device for giving an arbitrary Faraday-rotation angle or arbitrary attenuation to the lightwave signal of each channel in a wavelength division multiplex (WDM) in more detail about the optical device using the magneto-optical effect.
[0002]
[Description of the Prior Art] If a light beam passes through the inside of magneto optics crystals, such as YIG (yttrium iron garnet) placed into the magnetic field, a Faraday-rotation angle will be given to the light beam by the magneto-optical effect according to the thickness of the magnetization magnitude of a vector of a magneto optics crystal, a direction, and a magneto optics crystal. The optical device according to this principle is called a Faraday-rotation child, and the Faraday-rotation child made to impress a magnetic field to a magneto optics crystal with a permanent magnet is put in practical use. Since magnetization of the magneto optics crystal by the permanent magnet is uniform, in this Faraday-rotation child, its Faraday-rotation angle is usually eternal.
[0003] A good light variation attenuator is offered by combining a Faraday-rotation child and a polarizer. For example, the good light variation attenuator it was made to impress a magnetic field to a magneto optics crystal only with one electromagnet is indicated by JP,1-204021,A. However, when only one electromagnet is used, magnetization of a magneto optics crystal is not always saturated. If magnetization of a magneto optics crystal is not saturated, many magnetic domains will arise in a magneto optics crystal. Such existence of many magnetic domains worsens the repeatability of attenuation of an optical attenuator, and though good repeatability is secured, it makes adjustable [of attenuation / continuous] difficult. Moreover, attenuation with difficult control of dispersion of the light in the interface between many magnetic domains is produced.
[0004] By using combining an electromagnet and a permanent magnet, the optical device which made the Faraday-rotation angle adjustable while magnetization of a magneto optics crystal had been saturated is proposed by artificers (OAA and FDQ besides FUKUSHIMA, pp154- 157, 1996, or JP,6-51255,A). This optical device is a good light variation attenuator, and the property that attenuation changes continuously to 1.6dB - 25dB is acquired by changing drive current to 0mA - 40mA.
[0005] recent years -- low loss (for example, 0.2dB/(km)) -- the manufacturing technology and the used technology of an optical fiber are established, and the optical transmission system which makes an optical fiber a transmission line is put in practical use Moreover, in order to compensate the loss in an optical fiber and to enable long-distance transmission, use of the light amplifier for amplifying signal light is proposed, or it is put in practical use.
[0006] The light amplifier known conventionally is equipped with the optical-amplification medium by which the signal light which should be amplified is supplied, and the means which carries out the pumping (excitation) of the optical-amplification medium so that the gain band where an optical-amplification medium contains the wavelength of signal light may be offered. For example, erbium dope fiber amplifier (EDFA) is equipped with the pump light source for supplying to EDF the pump light which has the wavelength beforehand determined as the erbium dope fiber (EDF) as an optical-amplification medium. By setting the wavelength of pump light as 0.98-micrometer band or 1.48-micrometer band, the gain band containing the wavelength of 1.55 micrometers is obtained. Moreover, the light amplifier which has a semiconductor chip as an optical-amplification medium is also known. In this case, a pumping is performed by pouring current into a semiconductor chip.
[0007] On the other hand, there is a wavelength division multiplex (WDM) as technology for increasing the transmission capacity by one optical fiber. In the system by which WDM is applied, two or more optical carriers which have mutually different wavelength are used. The wavelength division multiplex of two or more lightwave signals obtained by modulating each optical carrier independently is carried out by the optical multiplexer, and the WDM

signal light obtained as a result is sent out to an optical-fiber-transmission way. In a receiving side, the received WDM signal light is made to separate into each lightwave signal by the optical demultiplexer, and transmission data are reproduced based on each lightwave signal. Therefore, according to the multiplex number concerned, the transmission capacity in one optical fiber can be increased by applying WDM.

[0008]

[Problem(s) to be Solved by the Invention] A transmission distance is restricted by the wavelength dependency of the gain represented with a gain inclination (gain tilt) or gain deflection when including a light amplifier in the system by which WDM is applied. For example, in EDFA, a gain inclination arises in near with a wavelength of 1.55 micrometers, and it is known that this gain inclination will change according to the input control power of the WDM signal light to EDFA and the power of pump light, the temperature of EDFA, etc.

[0009] In order to oppress the wavelength dependency of gain, after attenuating the lightwave signal of each channel by the optical attenuator which has suitable attenuation, performing a wavelength division multiplex may be proposed. In this case, although attenuation can be arbitrarily given to the lightwave signal of each channel by using two or more optical attenuators, an optical attenuator is needed only several channel minutes of WDM, and complicated composition or large-sized equipment is needed.

[0010] Therefore, the purpose of this invention is to offer the optical device of easy composition of that arbitrary attenuation can be given to the lightwave signal of each channel in a wavelength division multiplex (WDM).

[0011] Other purposes of this invention are to offer the optical device of easy composition of that arbitrary Faraday-rotation angles can be given to the lightwave signal of each channel in a wavelength division multiplex.

[0012] The purpose of further others of this invention becomes clear from the following explanation.

[0013]

[Means for Solving the Problem] According to the side with this invention, an optical device usable as a Faraday-rotation child who can give arbitrary Faraday-rotation angles according to position-conditions is offered. This optical device is equipped with the 1st and 2nd ports, the magneto optics crystal, and a means to impress a magnetic field to a magneto optics crystal. The 1st port is located in the 1st field and the 2nd port is located in the 2nd field. The 1st and 2nd ports are optically combined by the light beam. A magneto optics crystal is prepared so that a light beam may pass. A means to impress impresses a magnetic field to a magneto optics crystal so that it may have the distribution by which magnetization of a magneto optics crystal is a perpendicular flat surface substantially, and was given to the light beam.

[0014] When the 1st port is located in a certain position in the 1st field, the 1st port is optically combined with the 2nd port in a position [in the 2nd field]. When the 1st port is located in other positions in the 1st field, the 1st port is optically combined with the 2nd port in other positions where it corresponds in the 2nd field. Since magnetization of a magneto optics crystal has the given distribution, the Faraday-rotation angles given to a light beam differ according to the above-mentioned distribution in the time of being in the time of being in a position with the 1st port, and other positions. Therefore, offer of the optical device as a Faraday-rotation child who can give arbitrary Faraday-rotation angles according to position-conditions is attained.

[0015] For example, the 1st port is offered by two or more 1st installed optical fibers, and the 2nd port is offered by two or more 2nd installed optical fibers. In this case, each of two or more 1st optical fibers is optically combined with each to which two or more 2nd optical fibers correspond. And a different Faraday-rotation angle for every light beam which combines a corresponding fiber pair is acquired. Therefore, arbitrary Faraday-rotation angles can be given to the lightwave signal of each channel by making each of two or more 1st optical fibers correspond to the lightwave signal of each channel in a wavelength division multiplex. Moreover, since it ends with use of one magneto optics crystal to a multiple channel, the composition of an optical device becomes easy.

[0016] Faraday rotation of the light beam which passed the magneto optics crystal is carried out on operation of this optical device by the angle of rotation determined by the distribution of magnetization of the passage position concerned and a magneto optics crystal. Therefore, this optical device functions as an optical attenuator by adding the polarizer formed so that the light beam by which Faraday rotation was carried out may pass.

[0017] Desirably, a means to impress a magnetic field to a magneto optics crystal consists of two or more magnets, and two or more magnets contain at least one electromagnet for generating an adjustable magnetic field. The distribution of magnetization of a magneto optics crystal can be easily set up arbitrarily by changing by this the magnetic field given with at least one electromagnet.

[0018] Thus, when it is in the position to which the 1st port was fixed in the 1st field when a means to impress a magnetic field to a magneto optics crystal included a means to change the distribution of magnetization, it can be made to change according to the distribution of magnetization of the Faraday-rotation angle given to a light beam.

[0019] Desirably, a means to impress a magnetic field to a magneto optics crystal includes a means to saturate the intensity of magnetization of a magneto optics crystal, and a means to give change to the direction and strength of

magnetization. In this case, while it is prevented that many magnetic domains arise in a magneto optics crystal when the intensity of magnetization of a magneto optics crystal is saturated and the repeatability of a Faraday-rotation angle (or attenuation) becomes good, adjustable [of a Faraday-rotation angle (or attenuation) / continuous] becomes possible. Moreover, dispersion of the light in the interface between many magnetic domains decreases, and increase of attenuation [**** / un-] is prevented. By giving change to the direction and strength of magnetization, where the intensity of magnetization of a magneto optics crystal is saturated, the distribution of magnetization of a magneto optics crystal can be set up arbitrarily.
[0020] If based on the principle of operation of the optical device by this invention usable as above Faraday-rotation children, an optical device usable as an optical attenuator applicable to a wavelength division multiplex will be offered.

[0021] According to other sides of this invention, the optical device as the 1st composition of an optical attenuator is offered. Two or more 1st optical fibers to which this optical device is located in the 1st field, Two or more 2nd optical fibers which is optically combined with each of the optical fiber of this 1st plurality by the light beam respectively, and is located in the 2nd field, The magneto optics crystal prepared so that the above-mentioned light beam may pass, and a means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the distribution to which magnetization of this magneto optics crystal was substantially given to the above-mentioned light beam at the perpendicular flat surface, The 1st birefringence crystal which is prepared between two or more optical fibers of the above 1st, and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, It has the 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and two or more optical fibers of the above 2nd, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[0022] According to the side of further others of this invention, the optical device as the 2nd composition of an optical attenuator is offered. An optical fiber with this optical single device, and the dispersive device which combines this optical fiber with two or more light beams from which wavelength differs, Two or more optical fibers with which two or more of these light beams are combined, and the magneto optics crystal prepared so that two or more above-mentioned light beams may pass, A means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the distribution to which magnetization of this magneto optics crystal was substantially given to two or more above-mentioned light beams at the perpendicular flat surface, The 1st birefringence crystal which is prepared between the above-mentioned dispersive device and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, It has the 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and two or more above-mentioned optical fibers, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[0023] According to another side of this invention, the optical device as the 3rd composition of an optical attenuator is offered. The 1st dispersive device to which this optical device combines the 1st optical fiber and this 1st optical fiber with two or more light beams from which wavelength differs, The 2nd optical fiber and the 2nd dispersive device which combines two or more above-mentioned light beams with the 2nd optical fiber of the above, A means to impress a magnetic field to the above-mentioned magneto optics crystal so that it may have the magneto optics crystal prepared so that two or more above-mentioned light beams may pass, and the distribution to which magnetization of this magneto optics crystal was substantially given to two or more above-mentioned light beams at the perpendicular flat surface, The 1st birefringence crystal which is prepared between the 1st dispersive device of the above, and the above-mentioned magneto optics crystal, and combines each above-mentioned light beam with an ordinary ray component and an extraordinary-ray component, It has the 2nd birefringence crystal which is prepared between the above-mentioned magneto optics crystal and the 2nd dispersive device of the above, and combines the above-mentioned ordinary ray component and the above-mentioned extraordinary-ray component with each above-mentioned light beam.
[0024]
[Embodiments of the Invention] Hereafter, according to an accompanying drawing, the gestalt of desirable operation of this invention is explained in detail. Drawing 1 is the block diagram showing the operation gestalt of the Faraday-rotation child by this invention. This Faraday-rotation child has the 1st port 4 located in the 1st field 2, the 2nd port 8 located in the 2nd field 6, the magneto optics crystal 10, and the magnetic field impression unit 12. Each of ports 4 and 8 is offered by the excitation edge of an optical fiber in the illustrated example. Each port may be offered by the light emitting device or the photo detector.
[0025] Here, a magneto optics crystal 10 carries out Faraday rotation of the light beam outputted from the port 4,

Faraday rotation is carried out, and a ****** light beam is inputted into a port 8. The magnetic field impression unit 12 impresses a magnetic field to a magneto optics crystal 10 so that it may have the distribution to which magnetization of a magneto optics crystal 10 was substantially given to the light beam within the perpendicular flat surface. The 1st field 2 and the 2nd field 6 are determined that the light beam between a port 4 and 8 may pass a magneto optics crystal 10.

[0026] In the illustrated example, the magnetization vector inclines to the light beam as the distribution of the magnetization given to a magneto optics crystal 10 by the magnetic field impression unit 12 goes to a light beam under the upper shell in drawing within a perpendicular flat surface substantially. When a light beam passes the upper part portion in drawing of a magneto optics crystal 10 according to the distribution of such magnetization Since the size of a component parallel to the light beam of a magnetization vector is comparatively large A comparatively big Faraday-rotation angle is given to a light beam, and on the other hand, as shown by sign 4' and 8', ports 4 and 8 are located in drawing comparatively caudad. Since the size of a component parallel to the light beam of a magnetization vector becomes comparatively small when a light beam passes the lower part portion of a magneto optics crystal 10, the Faraday-rotation angle given to a light beam becomes smaller than the above-mentioned case.

[0027] Thus, arbitrary Faraday-rotation angles can be given to the light beam which combines between a port 4 and 8 according to the position-conditions of a field 2 and the ports 4 and 8 in six. Moreover, when making it the magnetic field impression unit 12 change the distribution of magnetization of a magneto optics crystal 10, it cannot be concerned with the position of ports 4 and 8, but arbitrary Faraday-rotation angles can be given to a light beam.

[0028] (A) - (C) of drawing 2 is drawing showing the operation gestalt of the magnetic field impression unit 12. In each of (A) - (C) of drawing 2 , a light beam shall pass a magneto optics crystal 10 in the direction which goes to the left from the direction which goes to the right from the left in drawing, or the right.

[0029] In the example shown in (A) of drawing 2 , the magnetic field impression unit 12 contains the magnet 13 for impressing a magnetic field to a magneto optics crystal 10 in the vertical direction in drawing, and the magnet 14 for impressing a magnetic field to the longitudinal direction in drawing at a magneto optics crystal 10. The magnet 14 has countered one edge of a magneto optics crystal 10.

[0030] According to this composition, the Faraday-rotation angle theta given to a light beam by the magneto optics crystal 10 decreases gently-sloping as it separates from the portion which counters the magnet 14 of a magneto optics crystal 10. This originates in the direction of the local magnetization in a magneto optics crystal 10 having a distribution as shown by the arrow all over drawing.

[0031] In the example shown in (B) of drawing 2 , the magnetic field impression unit 12 contains the magnet 13 for impressing the magnetic field of the vertical direction in drawing to a magneto optics crystal 10, and two magnets 16 and 18 for impressing a magnetic field at the longitudinal direction in drawing at a magneto optics crystal 10, respectively. The magnet 16 has countered one edge of a magneto optics crystal 10, and the magnet 18 has countered the other-end section of a magneto optics crystal 10.

[0032] According to this composition, the Faraday-rotation angle theta serves as the maximum in the position corresponding to the magnets 16 and 18 in a magneto optics crystal 10, respectively, and the Faraday-rotation angle theta serves as the minimum in the outline center section of the magneto optics crystal 10.

[0033] In the example shown in (C) of drawing 2 , the magnetic field impression unit 12 contains the magnet 13 for impressing the magnetic field of the vertical direction in drawing to a magneto optics crystal 10, and three magnets 20, 22, and 24 for impressing a magnetic field at the longitudinal direction in drawing at a magneto optics crystal 10, respectively. The magnet 20 has countered one edge of a magneto optics crystal 10, the magnet 24 has countered the other-end section of a magneto optics crystal 10, and the magnet 22 has countered the outline center section of the magneto optics crystal 10.

[0034] According to this composition, the Faraday-rotation angle theta serves as the maximum in the both ends and outline center section of the magneto optics crystal 10, and the Faraday-rotation angle theta serves as the minimum in the portion of a quadrant and the portion of 3/4 in the vertical direction in drawing of a magneto optics crystal 10.

[0035] In each of (A) - (C) of drawing 2 , when making it the intensity of magnetization of a magneto optics crystal 10 saturated by the magnetic field given only with a magnet 13, the curve showing the relation between the Faraday-rotation angle theta and a position can be made continuous, and, moreover, repeatability of this relation can be made good.

[0036] Drawing 3 is the perspective diagram showing other operation gestalten of the magnetic field impression unit 12. Here, the magnetic field impression unit 12 contains one permanent magnet 26 which impresses a magnetic field to a magneto optics crystal 10, and two or more electromagnets 28.

[0037] The sign 30 shows the propagation direction of the light beam which passes a magneto optics crystal 10. The direction of the magnetic field impressed to a magneto optics crystal 10 with a permanent magnet 26 is the propagation direction 30 and outline perpendicular of a light beam, and the directions of the magnetic field impressed to a magneto

optics crystal 10 by each of a permanent magnet 28 are the propagation direction 30 of a light beam, and outline parallel.
[0038] According to this composition, since a magnetic field can be impressed effective in a magneto optics crystal 10 with a permanent magnet 26, the intensity of magnetization of a magneto optics crystal 10 can be saturated easily. Moreover, since the direction and strength of magnetization can be easily changed ON / by turning off or adjusting, the distribution of magnetization of a magneto optics crystal 10 can be set up arbitrarily easily. [in / each portion of a magneto optics crystal 10 / for the current supplied to each of an electromagnet 28]
[0039] Drawing 4 is the block diagram showing other operation forms of the Faraday-rotation child by this invention. Two or more fiber collimators 32 (#1, --, #n) and two or more fiber collimators 34 (#1, --, #n) optically combined with the fiber collimator 32 (#1, --, #n) by the parallel light beam, respectively are formed. Each of the fiber collimator 32 (#1, --, #n) functions as the 1st port 4 of drawing 1 , and each of the fiber collimator 34 (#1, --, #n) functions as the 2nd port 8 of drawing 1 .
[0040] Each fiber collimator consists of sleeves for holding an optical fiber and a lens so that it may have the physical relationship as which the optical fiber, the lens, and the excitation edge and lens of an optical fiber were determined beforehand.
[0041] According to this operation form, while making the fiber collimator 32 (#1, --, #n) correspond to the lightwave signal of each channel of WDM signal light, arbitrary Faraday-rotation angles can be given to the lightwave signal of each channel by adopting the operation form of drawing 3 as a magnetic field impression unit 12. Moreover, since the common magneto optics crystal 10 is applicable to a multiple channel, an equipment configuration can be simplified.
[0042] Drawing 5 is the block diagram showing the 1st operation form of the optical attenuator by this invention. This optical attenuator is characterized at the point additionally equipped with the polarizer 36 formed so that the light beam Faraday rotation was carried out [the light beam] by the magneto optics crystal 10 may pass as contrasted with the Faraday-rotation child shown in drawing 4 .
[0043] The joint efficiency between each of the fiber collimator 32 (#1, --, #n) and each to which the fiber collimator 34 (#1, --, #n) corresponds, i.e., attenuation, is determined according to the polarization state of each light beam in which the plane of polarization and magneto optics crystal 10 of the light which passes a polarizer 36 carried out Faraday rotation. Therefore, arbitrary attenuation can be given to the lightwave signal of each channel by applying this optical attenuator to WDM.
[0044] Drawing 6 is the block diagram showing the 1st operation form of the optical transmitter for WDM by this invention. Here, the optical attenuator module 38 corresponding to the 1st operation form of an optical attenuator shown in drawing 5 is used.
[0045] The light source 40 (#1, --, #n) is optically connected to the fiber collimator 32 (#1, --, #n) of the optical attenuator module 38, respectively. The light source 40 (#1, --, #n) is wavelength lambda 1, --, lambdan, respectively. A lightwave signal is outputted. The indirect modulation using the direct modulation or the extraneous light modulator to each light source can be applied to the modulation for obtaining each lightwave signal.
[0046] The lightwave signal outputted from the light source 40 (#1, --, #n) receives different attenuation according to the principle mentioned above in the optical attenuator module 38, and the wavelength division multiplex of two or more decreased lightwave signals is carried out by the optical multiplexer 42. The WDM signal light obtained as a result of the wavelength division multiplex is sent out to the optical-fiber-transmission way which it is amplified by the light amplifier 44 and illustrated.
[0047] When the wavelength of WDM signal light is contained in 1.55-micrometer band (1.50 or 1.60 micrometers), erbium dope fiber amplifier (EDFA) can be adopted as a light amplifier 44. EDFA is equipped with the erbium dope fiber (EDF) with which the erbium was doped, the pump light source which outputs pump light, and the optical circuit for supplying pump light and the WDM signal light which should be amplified to EDF. The wavelength of pump light is contained in for example, 0.98-micrometer band (0.97 or 0.99 micrometers) or 1.48-micrometer band (1.47 or 1.49 micrometers).
[0048] Drawing 7 is drawing showing the example of the wavelength property of the gain of a light amplifier. The vertical axis shows optical power, the horizontal axis shows wavelength, and the spectrum of the WDM signal light amplified by EDFA is shown. This spectrum has the configuration superimposed on the steep spectrum of the lightwave signal of each channel by the comparatively gently-sloping spectrum of ASE (amplified spontaneous-emission light) generated in EDFA.
[0049] In EDFA, it is known that a comparatively simple gain inclination will arise in near with a wavelength of 1550nm, and this gain inclination is reflected in the configuration of the spectrum of ASE. Here, the gain inclination to which gain becomes small is shown as wavelength becomes long.
[0050] With such existence of a gain inclination, though the loss in a part for the power of the lightwave signal

outputted from the light source 40 (#1, --, #n) of drawing 6 and each connection is equal, as it is shown in drawing 7 , according to a gain inclination, the power of a lightwave signal changes for every channel.

[0051] The optical attenuator by this invention is very effective in order to cope with such a gain inclination. That is, since the distribution of magnetization of a magneto optics crystal 10 can be easily set up in order to compensate a comparatively simple gain inclination, level deflection between channels of the amplified WDM signal light which is outputted from the optical transmitter for WDM can be effectively made small by applying this invention to the optical attenuator module 38 of drawing 6 .

[0052] Reference of drawing 8 shows the conventional technology of the optical transmitter for WDM. Here, it replaces with the optical attenuator 38 to which this invention of drawing 6 is applied, and two or more optical attenuators ATT are shown.

[0053] Although level deflection between channels of the WDM signal light amplified by setting up attenuation of each optical attenuator appropriately also by this conventional technology can be made small, since an optical attenuator is needed only several channel minutes, an equipment configuration becomes complicated.

[0054] On the other hand, with the operation gestalt of drawing 6 , when this invention is applied, since the optical attenuator module 38 is applicable common to the multiple channel of WDM, an equipment configuration becomes easy.

[0055] Drawing 9 is the block diagram showing the 2nd operation form of the optical attenuator by this invention. In order to make this optical attenuator usable as an optical attenuator module 38 of drawing 6 , the 1st optical fiber array 46 and the 2nd optical fiber array 48 are formed. Each optical fiber of the 1st optical fiber array 46 functions as the 1st port 4 of drawing 1 , and each optical fiber of the 2nd optical fiber array 48 functions as the 2nd port 8 of drawing 1 .

[0056] In order to combine optically each optical fiber of the 1st optical fiber array 46, and each optical fiber of the 2nd optical fiber array 48 by the convergence light beam, the lens 50 which counters the optical fiber array 46, and the lens 52 which counters the optical fiber array 48 are formed.

[0057] It is the same as that of an old operation gestalt that the magneto optics crystal 10 and the magnetic field impression unit 12 are used. The magneto optics crystal 10 is formed so that each light beam may pass.

[0058] The 1st birefringence crystal 54 is formed between a lens 50 and a magneto optics crystal 10, and the 2nd birefringence crystal 56 is formed between the magneto optics crystal 10 and the lens 52. Each of the birefringence crystals 54 and 56 consists [here] of birefringence matter, such as a rutile, and is monotonous, and each optical axis inclines 45 degrees of outlines to each light beam, as shown by the arrow all over drawing.

[0059] the wedge board of the birefringence crystals 54 and 56 which consists of birefringence matter if respectively can also be used (the following -- the same) In this case, lenses 50 and 52 are chosen so that not a convergence light beam but an parallel light beam may be obtained.

[0060] The 1st birefringence crystal 54 combines each light beam with an ordinary ray component and an extraordinary-ray component. The 2nd birefringence crystal 56 combines an ordinary ray component and an extraordinary-ray component with each light beam.

[0061] Drawing 10 is drawing showing the principle of operation of the optical attenuator shown in drawing 9 . The sign 58 expresses a certain optical fiber in the optical fiber array 46, and the sign 60 expresses the optical fiber combined with the optical fiber 58 in the optical fiber array 48.

[0062] According to the situation of the optical coupling between an optical fiber 58 and 60, he can understand operation of the optical attenuator of drawing 9 . The light emitted from excitation edge 58A of an optical fiber 58 serves as a beam 62 with a lens 50. A beam 62 is divided into the beams 64 and 66 which carry out considerable to the ordinary ray and extraordinary ray in the 1st birefringence crystal 54, respectively.

[0063] Beams 64 and 66 are mutually parallel, and are outputted from the position where the birefringence crystals 54 differ slightly. Beams 64 and 66 can give the almost same Faraday-rotation angle, and are outputted by the magneto optics crystal 10 as beams 68 and 70, respectively.

[0064] A beam 68 is divided into the beams 72 and 74 which carry out considerable to the ordinary ray and extraordinary ray in the 2nd birefringence crystal 56, respectively. A beam 70 is divided into the beams 76 and 78 which carry out considerable to the ordinary ray and extraordinary ray in the birefringence crystal 56, respectively.

[0065] Supposing the birefringence crystals 54 and 56 are mutually parallel and such thickness is equal, beams 72 and 78 overlap mutually. Therefore, beams 72 and 78 can be converged with a lens 52, and can be combined with excitation edge 60A of an optical fiber 60. Beams 74 and 76 swerve from beams 72 and 78, and are removed.

[0066] The ratio (namely, attenuation) to the power of the input beam of the total power of beams 72 and 78 is dependent on the Faraday-rotation angle in a magneto optics crystal 10. This Faraday-rotation angle is determined by the distribution of magnetization of the magneto optics crystal 10 by the magnetic field impression unit 12, and the position of beams 64 and 66. Therefore, arbitrary attenuation can be given to the lightwave signal of each channel in

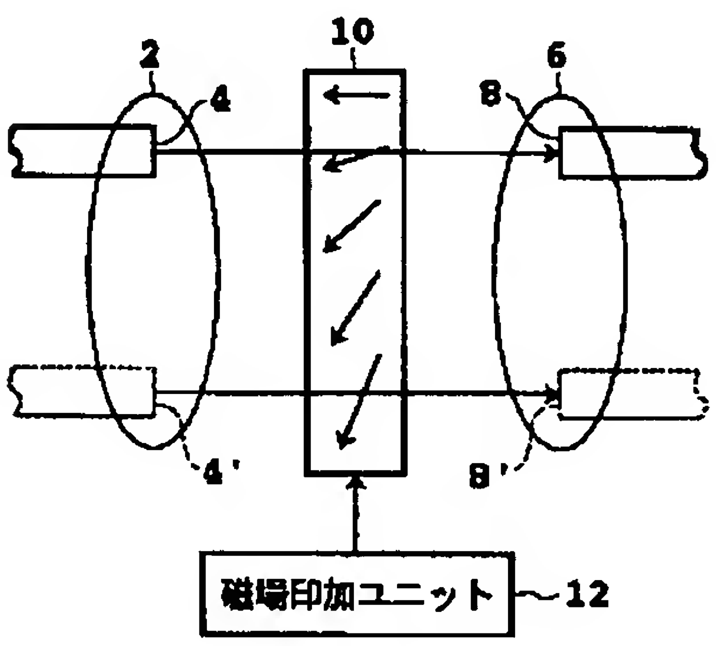
WDM by using the optical attenuator of drawing 9 as an optical attenuator module 38 of drawing 6 .
[0067] Moreover, if the Faraday-rotation angle given by the magneto optics crystal 10 is the same, the total power of beams 72 and 78 will not be dependent on the polarization state of an input beam. Therefore, it cannot be concerned with the polarization state of the lightwave signal of each channel, but desired attenuation can be given to the lightwave signal concerned.
[0068] Thus, according to the operation gestalt of drawing 9 , offer of the optical non-depended polarization attenuator module 38 (refer to drawing 6) is attained. Although the operation gestalt of drawing 9 explained operation towards going to the optical fiber array 48 from the optical fiber array 46, operating similarly towards going to the optical fiber array 46 from the optical fiber array 48 cannot be overemphasized.
[0069] Drawing 11 is the block diagram showing the 3rd operation gestalt of the optical attenuator by this invention. In order to add the function of the optical multiplexer 42 to the function of the optical attenuator module 38 of drawing 6 , it is made to combine one port and two or more ports here.
[0070] Therefore, it replaces with the 1st optical fiber array 46 of drawing 9 , the single optical fiber 80 is formed, and the dispersive device 82 is formed between a lens 50 and the 1st birefringence crystal 54. A dispersive device 82 is combined with two or more light beams from which wavelength differs an optical fiber 80. Since he can understand according to the principle of operation of drawing 10 about the combination accompanied by attenuation with each of two or more light beams, and each optical fiber of the optical fiber array 48, the explanation is omitted.
[0071] Reference of (A) of drawing 12 and (B) shows the operation gestalt of the dispersive device which can be used as a dispersive device 82 of drawing 11 . The dispersive device shown in (A) of drawing 12 is the reflected type grating 84, and a grating 84 makes the input beam given by WDM signal light diffract at a different angle for every wavelength of a lightwave signal. Specifically, the angle which the lightwave signal and input beam of short wavelength make comparatively is smaller than the angle which the lightwave signal and input beam of long wavelength make comparatively.
[0072] The dispersive device shown in (B) of drawing 12 is prism 86. Prism 86 makes the input beam given by WDM signal light refracted with different angle of refraction for every wavelength of a lightwave signal. Specifically, the angle of refraction of the lightwave signal of short wavelength is comparatively larger than the angle of refraction of the lightwave signal of long wavelength comparatively.
[0073] Thus, since a light beam is spatially separable by using a dispersive device according to wavelength, different attenuation according to wavelength can be given to a light beam by setting up the distribution of magnetization of a magneto optics crystal 10 according to this invention.
[0074] In addition, in drawing 11 , although the arrow showing the propagation direction of each light beam is going to the optical fiber array 48 from the optical fiber 80, it is the same as the operation gestalt of drawing 9 that the optical attenuator of drawing 11 operates in reversible.
[0075] Drawing 13 is the block diagram showing the 2nd operation gestalt of the optical transmitter for WDM by this invention. Here, the optical attenuator shown in drawing 11 is used as an optical attenuator / an optical multiplexer module 88, the optical fiber array 48 is optically connected to the light source 40 (#1, --, #n), and the optical fiber 80 is optically connected to the light amplifier 44.
[0076] Since only the optical attenuator shown in drawing 11 can perform the function of the optical attenuator module 38 shown in drawing 6 , and the optical multiplexer 42 according to this operation gestalt, composition of the optical transmitter for WDM can be simplified.
[0077] Drawing 14 is the block diagram showing the 4th operation gestalt of the optical attenuator by this invention. Here, in order to combine one port and other one port by two or more light beams from which the wavelength which passes a magneto optics crystal 10 differs, it replaces with the optical fiber array 48 of drawing 11 , and the single optical fiber 90 is used. And in order to combine with an optical fiber 90 two or more light beams given by the dispersive device 82, another dispersive device 92 is formed between the 2nd birefringence crystal 56 and the lens 52.
[0078] Since he can understand about the attenuation given to each of two or more light beams according to the principle of operation of drawing 10 , the explanation is omitted. In order to press down small the joint loss between an optical fiber 80 and an optical fiber 90, it is desirable to use the thing same as a dispersive device 92 as a dispersive device 82.
[0079] In addition, although the arrow showing the propagation direction of each light beam has turned to the optical fiber 90 from the optical fiber 80 in drawing 14 , it is the same as the operation gestalt of drawing 11 that the optical attenuator shown in drawing 14 operates in reversible. Drawing 15 is the block diagram showing the 3rd operation gestalt of the optical transmitter for WDM by this invention. Here, the optical attenuator shown in drawing 14 is used as an optical demultiplexer / optical attenuator / an optical multiplexer module 94.
[0080] The wavelength division multiplex of the lightwave signal outputted from the light source 40 (#1, --, #n) is

carried out by the direct light multiplexer 42, and the WDM signal light obtained as a result is amplified by the light amplifier 44. The amplified WDM signal light is sent out to the optical-fiber-transmission way which is not illustrated through a module 94.
[0081] By the module 94, the attenuation according to the position which passes a magneto optics crystal 10 is given to the lightwave signal of each channel of WDM signal light. Therefore, desired attenuation can be given to each lightwave signal by setting up the distribution of magnetization of a magneto optics crystal 10 appropriately according to this invention. Therefore, a module 94 will function as an optical equalizer.
[0082] A module 94 and connection sequence of a light amplifier 44 are made reverse, and after giving desired attenuation to each lightwave signal, you may make it amplify WDM signal light by the light amplifier 44, although the WDM signal light amplified by the light amplifier 44 is supplied to the module 94 with the operation gestalt of drawing 15 .
[0083] Although the module 94 is formed in the optical transmitter for WDM, a module 94 is formed in the middle of an optical-fiber-transmission way, and you may make it oppress the level deflection between channels of WDM accumulated by use of two or more alignment light repeaters which contain a light amplifier respectively with the operation gestalt of drawing 15 .
[0084] Thus, in addition to the function of the optical attenuator by this invention, the function of an optical demultiplexer and an optical multiplexer is obtained by using two dispersive devices 82 and 92, as shown in drawing 14 .
[0085] Drawing 16 is the block diagram showing the 5th operation gestalt of the optical attenuator by this invention. Here, to the field of the center of a magneto optics crystal 10, in view of a geometrically symmetrical thing, the principal part of the optical attenuator of drawing 14 forms a mirror 93 in one field of magneto-optics-crystal 10', and is omitting the birefringence crystal 56, the dispersive device 92, the lens 52, and optical fiber 90 of drawing 14 .
[0086] As a dispersive device 82, the reflected type gratings 94 and 96 of a couple with an equal grating constant are used, and when the input beam to a dispersive device 82 is a collimated beam, it is made for an output beam to also turn into a collimated beam by this.
[0087] Moreover, in order to make a collimated beam suit, the wedge board which consists of birefringence matter, such as a rutile, is used as birefringence crystal 54'. In order to separate spatially the WDM signal light supplied to the optical fiber 80, and the WDM signal light which is outputted from an optical fiber 80 and which was able to give desired attenuation to the lightwave signal of each channel, the optical circulator 100 is used.
[0088] It functions as an optical circulator 100 having three ports 100A, 100B, and 100C, outputting the light supplied to port 100A from port 100B, and outputting the light supplied to port 100B from port 100C.
[0089] As a magnetic field impression unit 12, the magnetic field impression unit shown in drawing 3 is adopted. The drive current controlled by the control circuit 98 is supplied to each electromagnet 28.
[0090] According to this operation gestalt, since the thickness of magneto-optics-crystal 10' can be substantially managed with a half to the thickness of the operation gestalt 10 of drawing 14 , the amount of the expensive magneto optics crystal used is cut down, and low-cost-ization is attained. Moreover, since there are few part mark and they end, the further low-cost-ization is attained.
[0091] Furthermore, since a mirror 93 is formed in one field of magneto-optics-crystal 10', a light beam reflects by the mirror 93 and it is made to go and come back to the inside of magneto-optics-crystal 10', the flexibility of the arrangement gestalt of the electromagnet 28 for impressing a magnetic field especially to each beam and the same direction increases.
[0092]
[Effect of the Invention] As explained above, according to this invention, the effect that offer of the optical device of easy composition of that an arbitrary Faraday-rotation angle or arbitrary attenuation can be given to the lightwave signal of each channel in a wavelength division multiplex (WDM) is attained arises.

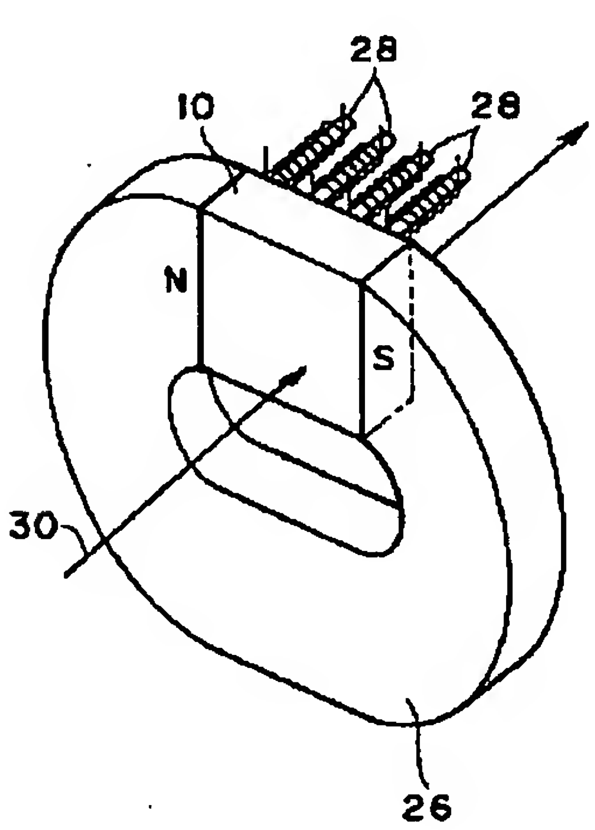
[Translation done.]

DRAWINGS

[Drawing 1]
ファラデー回転子の実施形態を示すブロック図

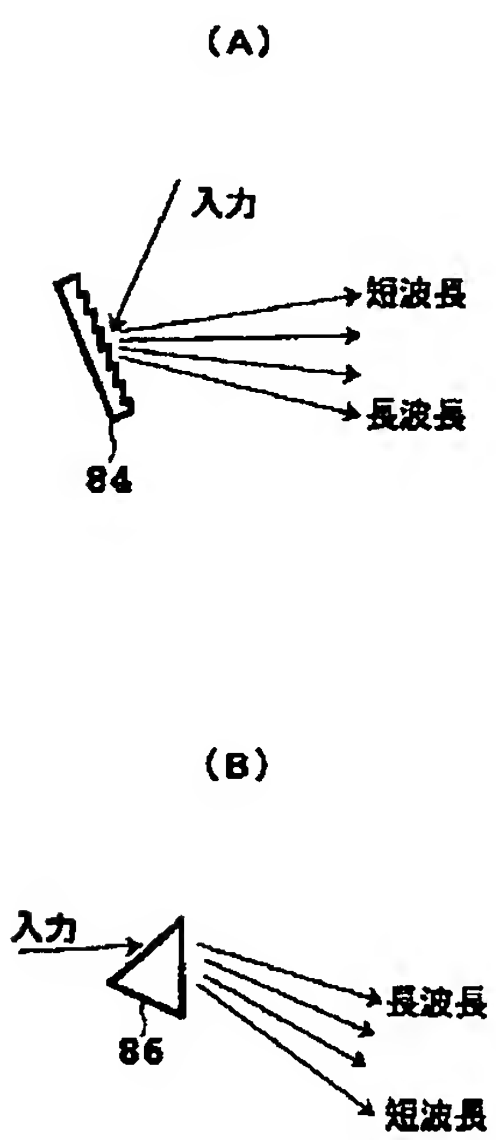


[Drawing 3]
磁場印加ユニットの他の実施形態を示す斜視図

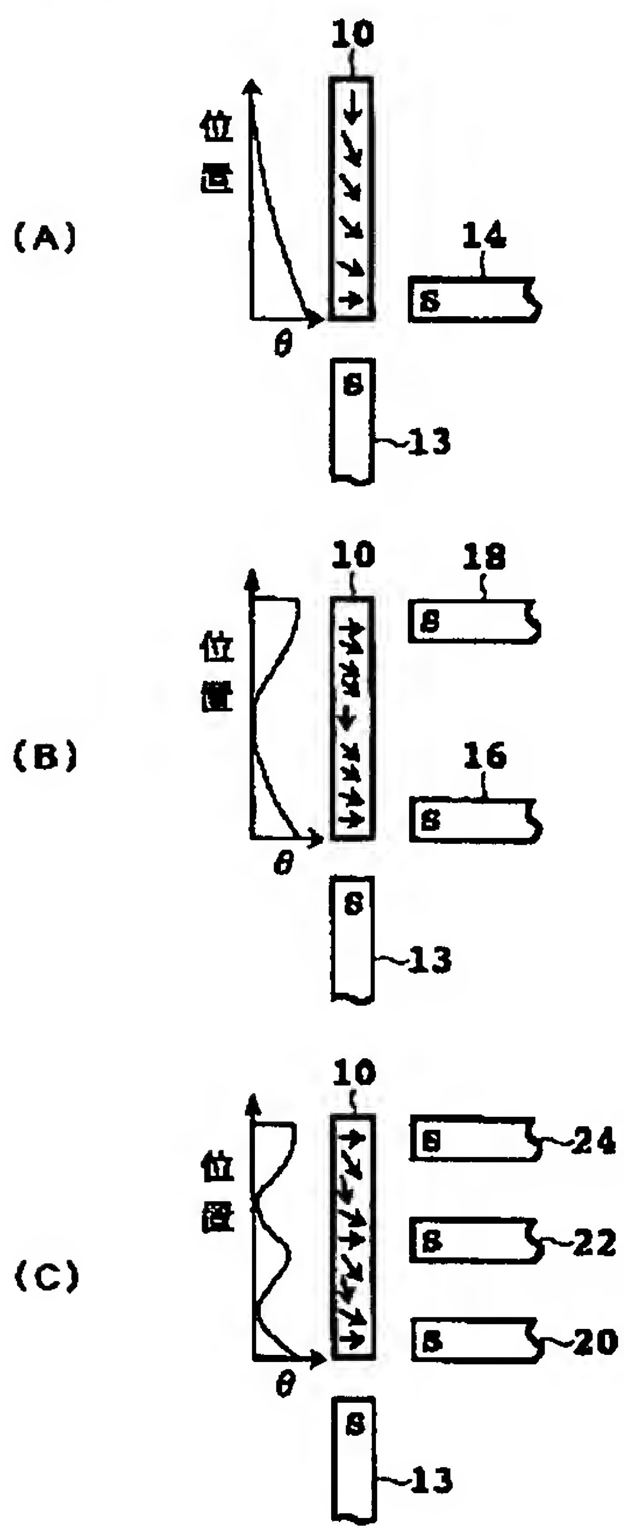


[Drawing 12]

分散素子の実施形態を示す図

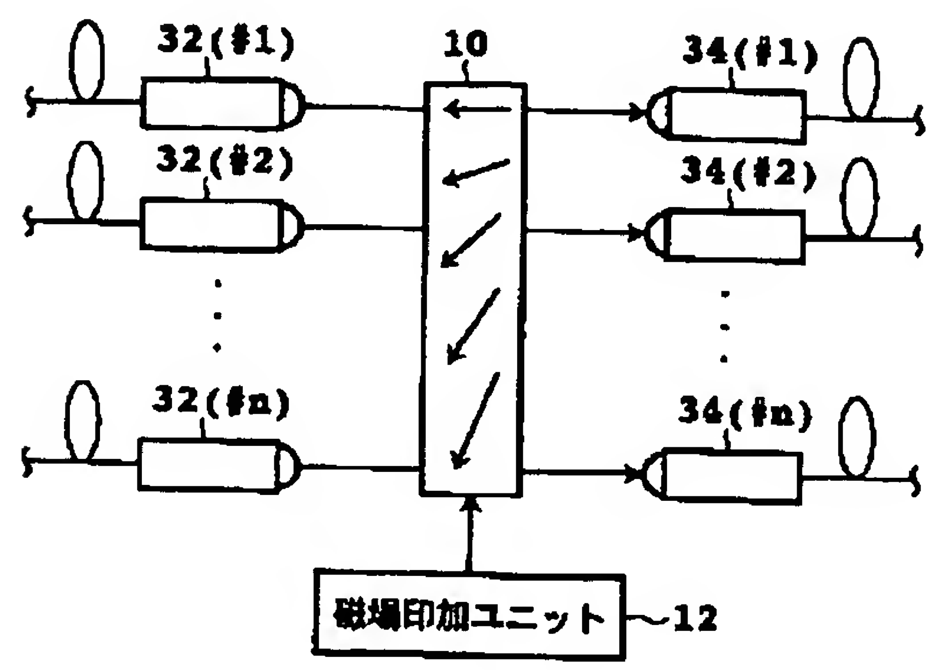


[Drawing 2]
磁場印加ユニットの実施形態を示す図



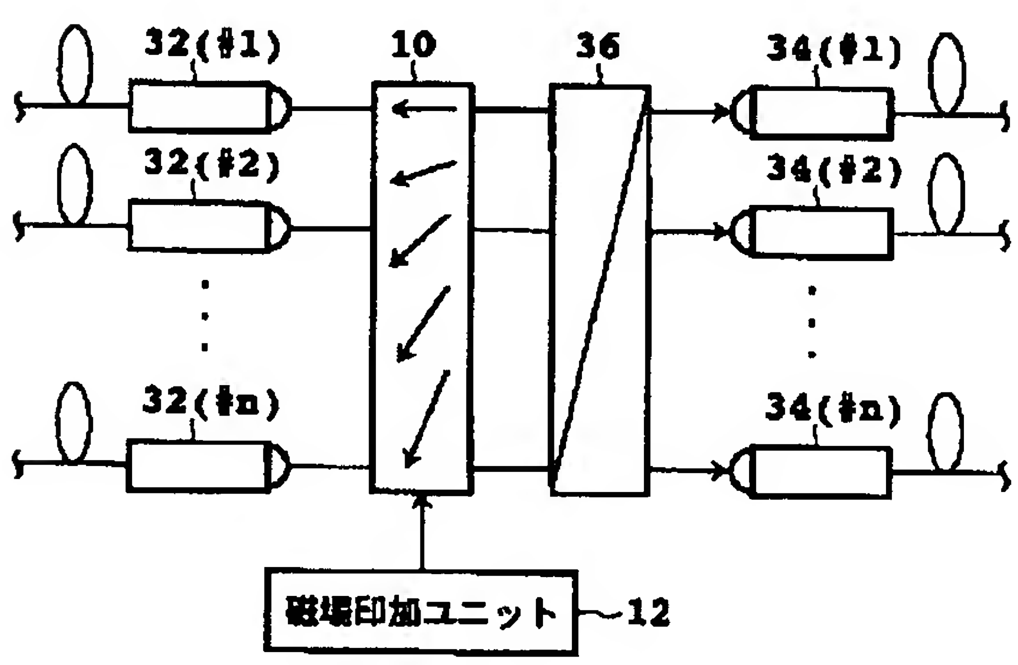
[Drawing 4]

ファラデー回転子の他の実施形態を示すブロック図



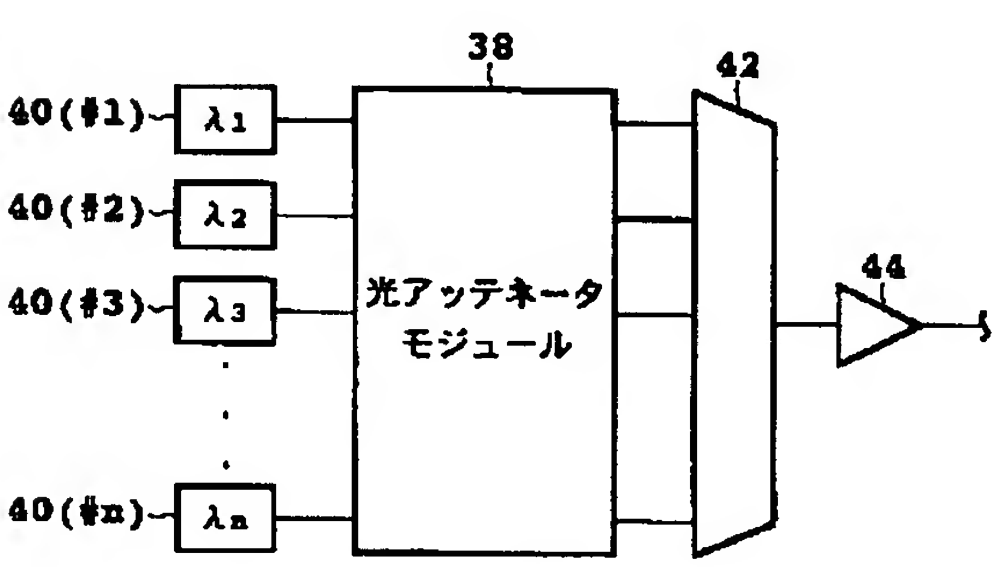
[Drawing 5]

光アッテネータの第１実施形態を示すブロック図



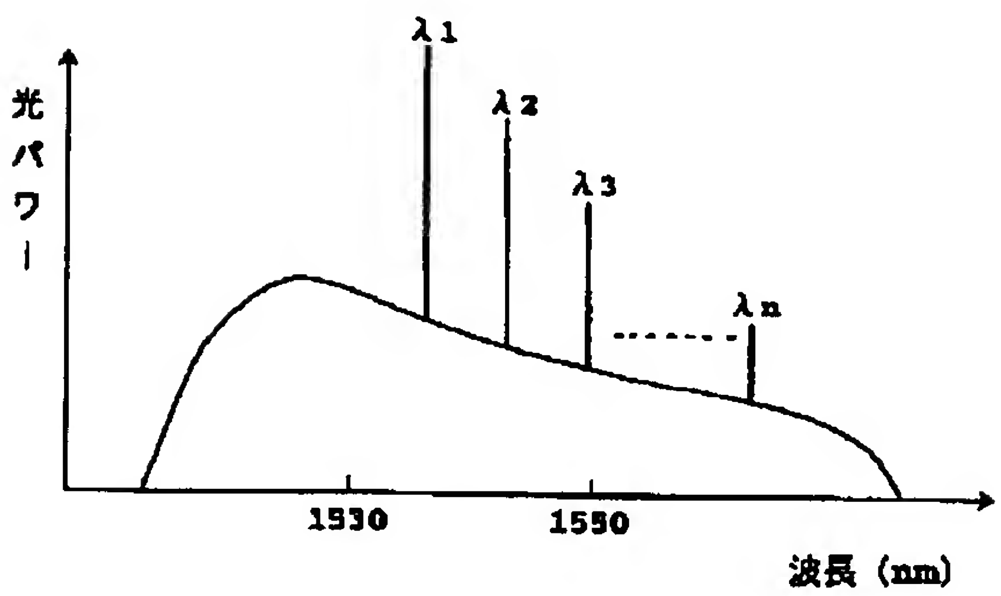
[Drawing 6]

ＷＤＭ用光送信機の第１実施形態を示すブロック図

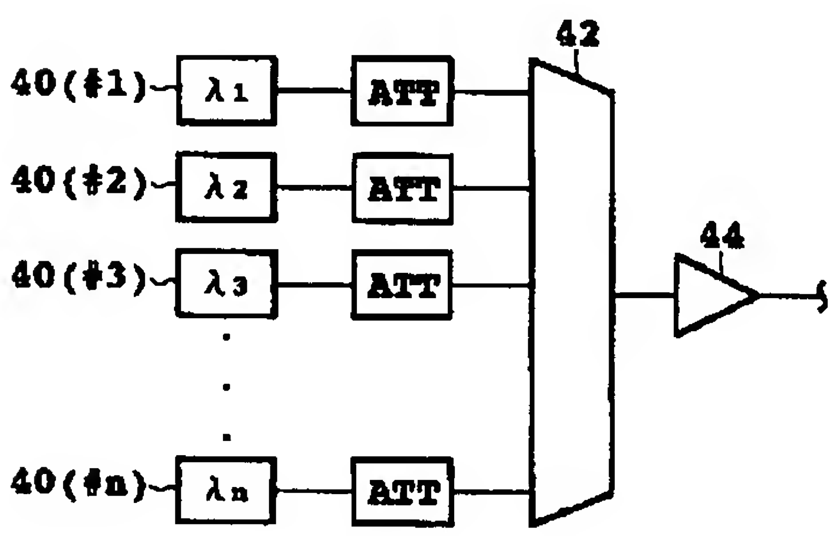


[Drawing 7]

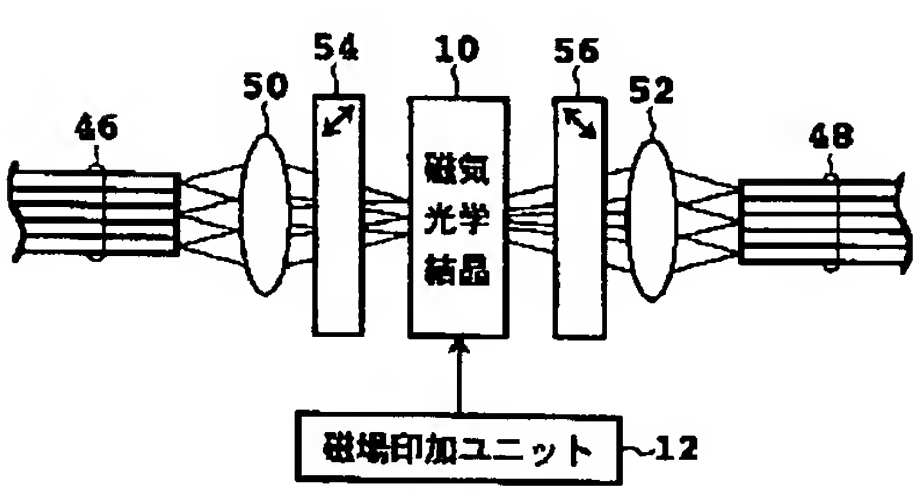
光増幅器の利得の波長特性の例を示す図



[Drawing 8]
ＷＤＭ用光送信機の従来技術を示すブロック図

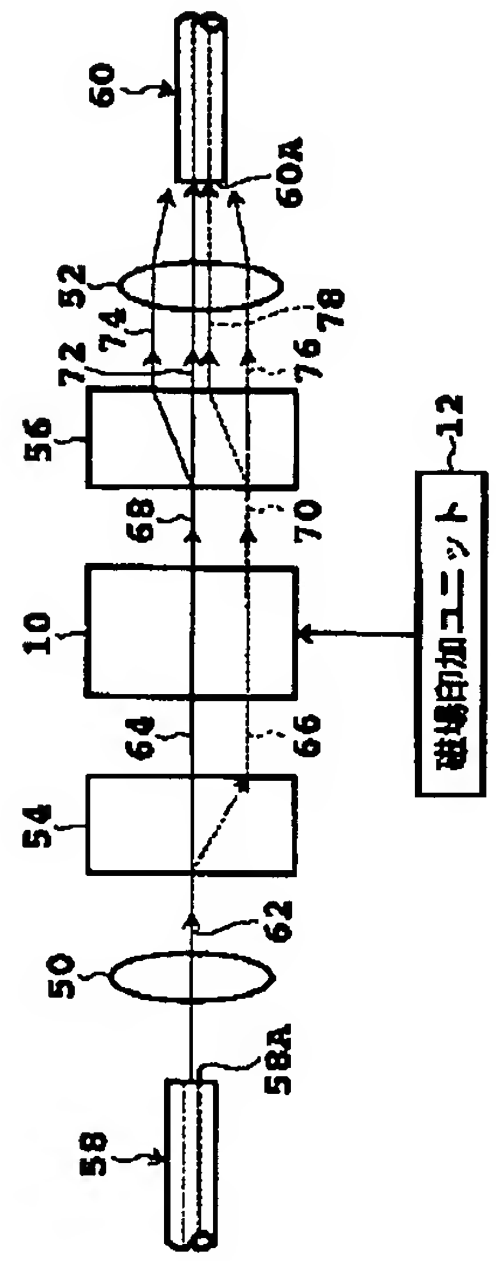


[Drawing 9]
光アッテネータの第２実施形態を示すブロック図

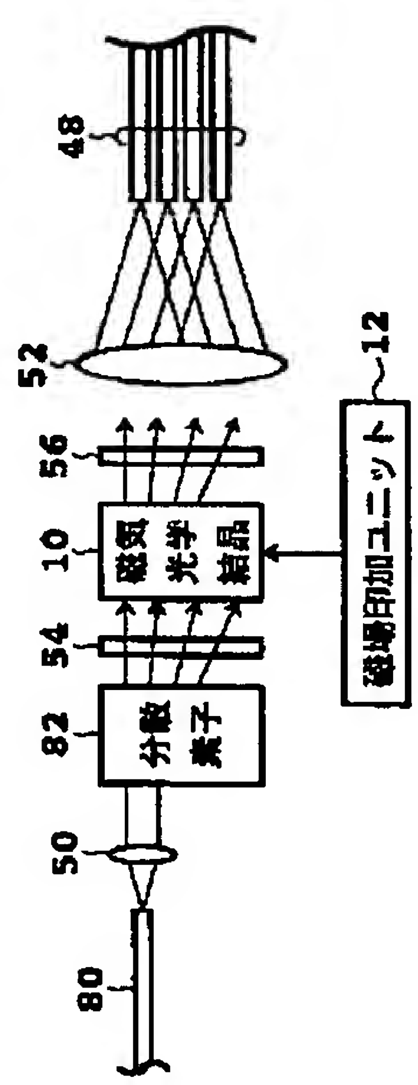


[Drawing 10]

図９の光アッテネータの動作原理を示す図

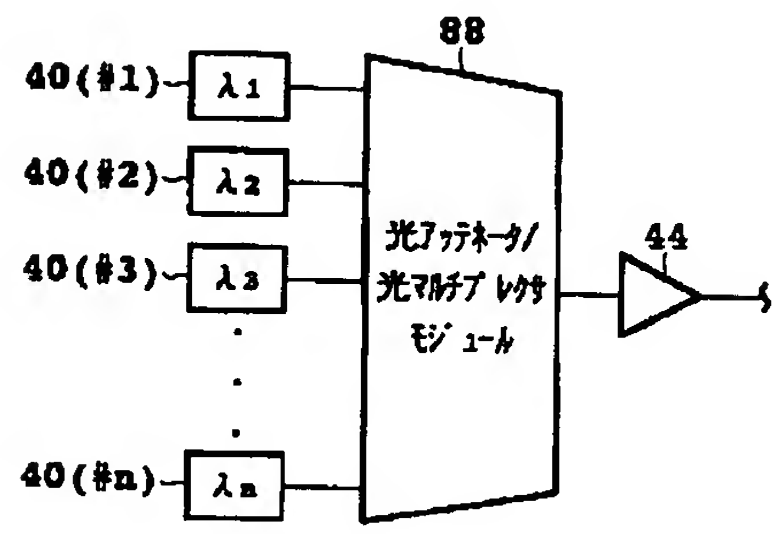


[Drawing 11]
光アッテネータの第３実施形態を示すブロック図

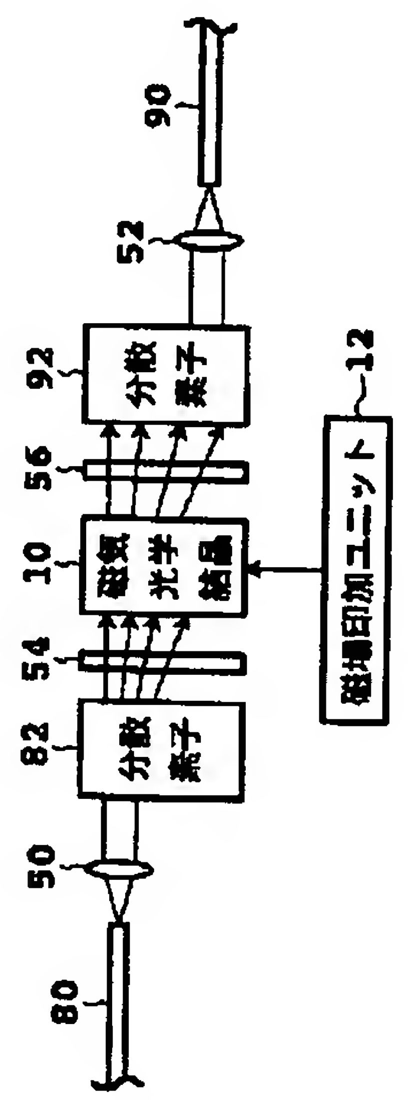


[Drawing 13]

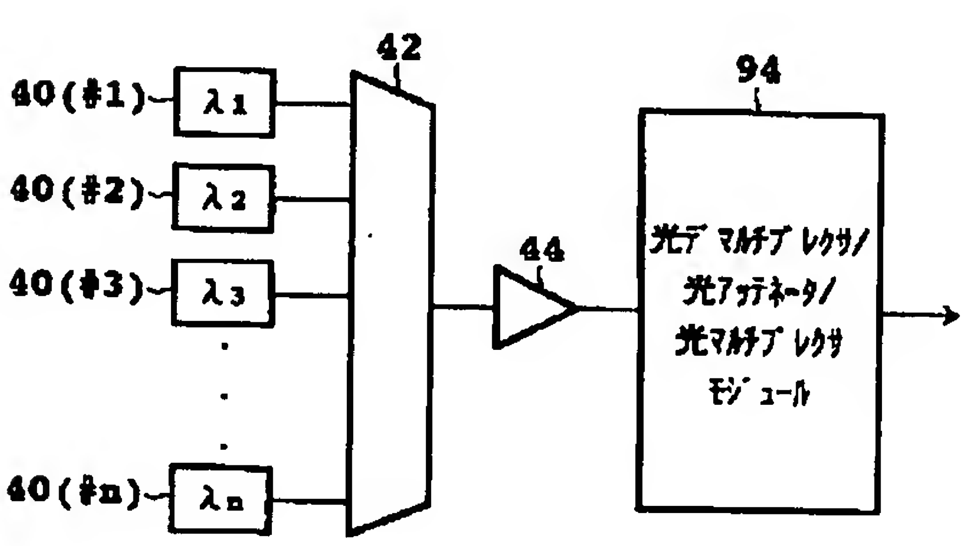
ＷＤＭ用光送信機の第２実施形態を示すブロック図



[Drawing 14]
光アッテネータの第４実施形態を示すブロック図

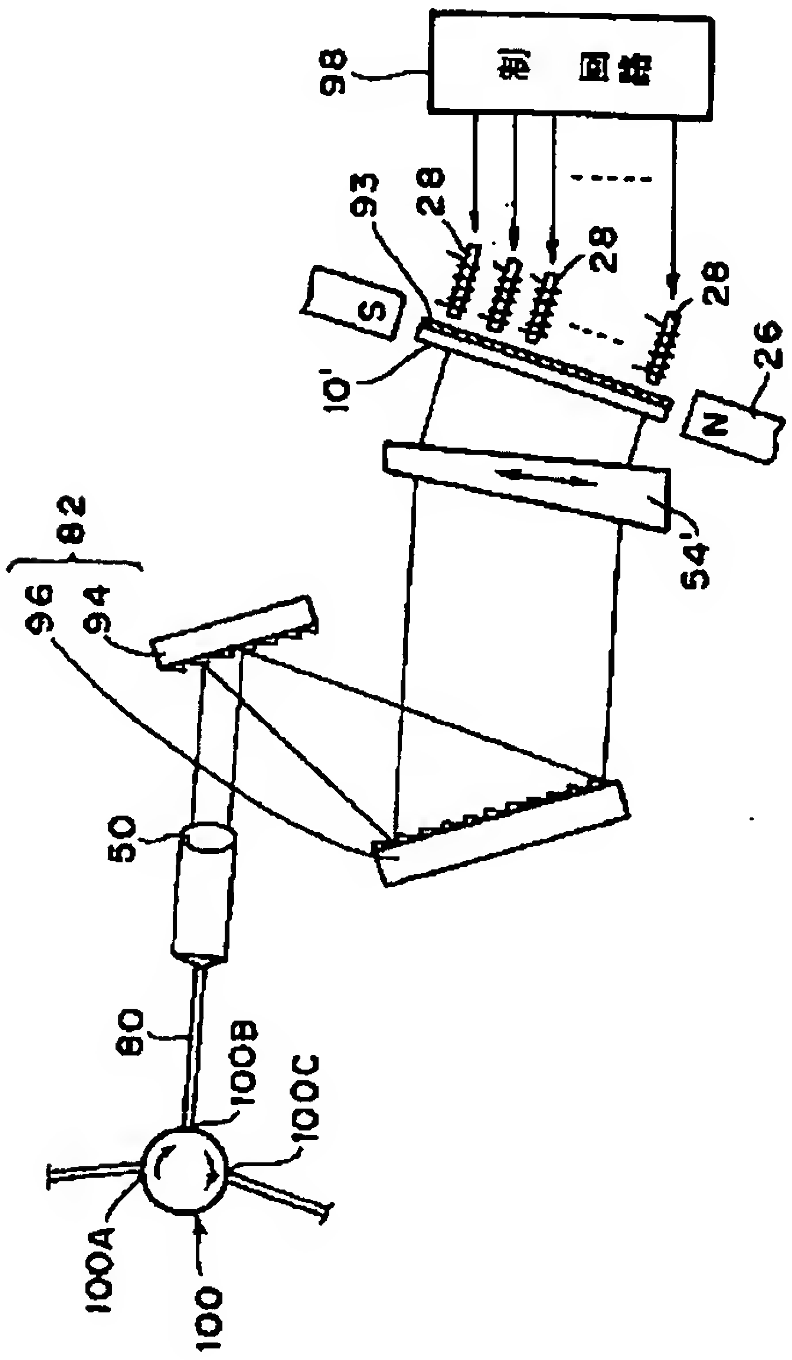


[Drawing 15]
ＷＤＭ用光送信機の第３実施形態を示すブロック図



[Drawing 16]

光アッテネータの第５実施形態を示すブロック図



[Translation done.]